Main Injector Neutrino Oscillation Search

DOE Site Visit, Sep 8 2009

Mary Bishai
Brookhaven National Laboratory

September 8, 2009

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The NuMI/MINOS Accelerator ν_μ Experiment

Observe $\nu_\mu/\bar{\nu}_\mu$ disappearance, ν_e appereance, atmospheric $\nu/\bar{\nu}$ oscillations, search for ν_s

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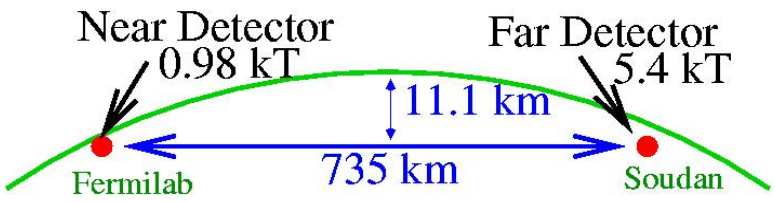
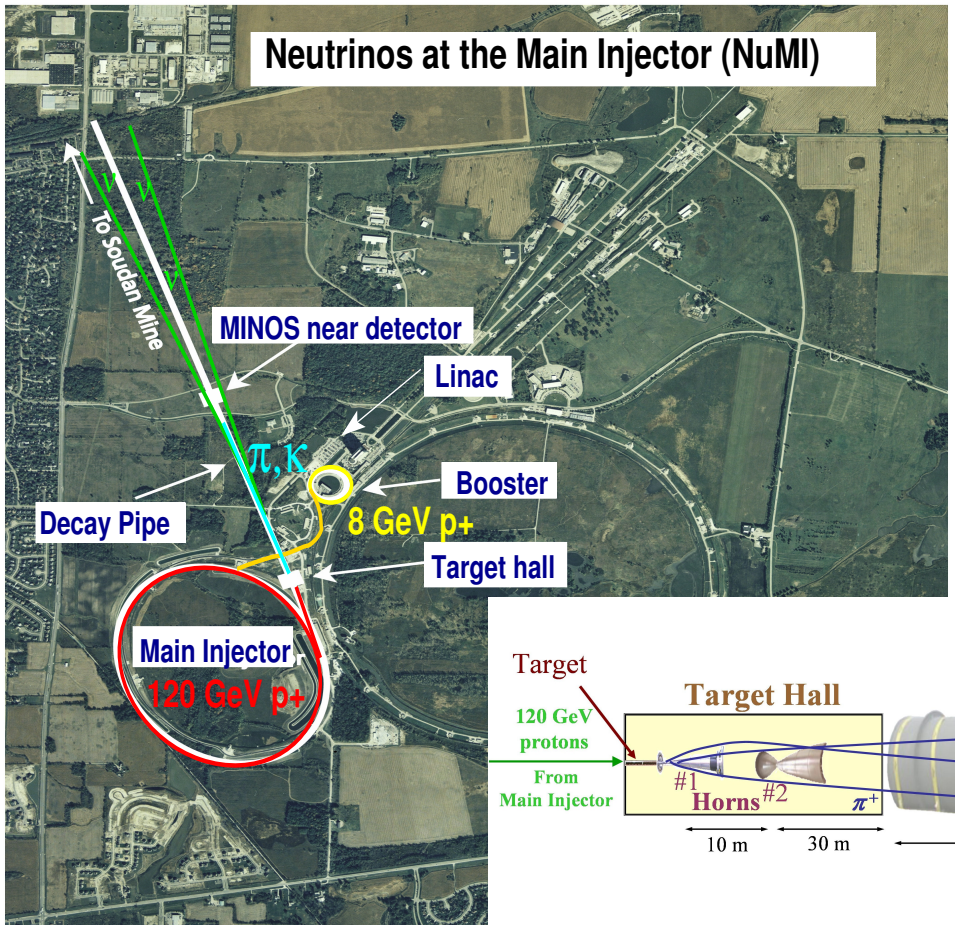
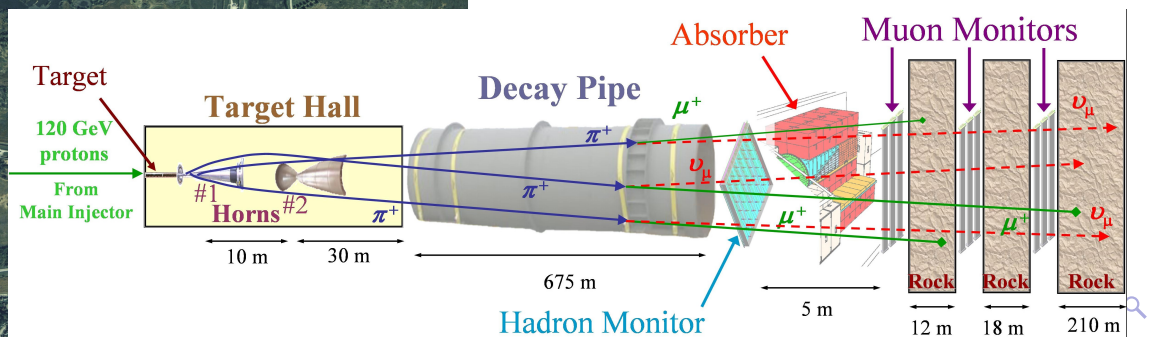


Fermi Natl. Lab., IL **Soudan Underground Lab, MN**



NuMI Horn 2 inner conductor
Radial field, B $\propto$ 1/r

3T at 200 kA



The MINOS Detectors

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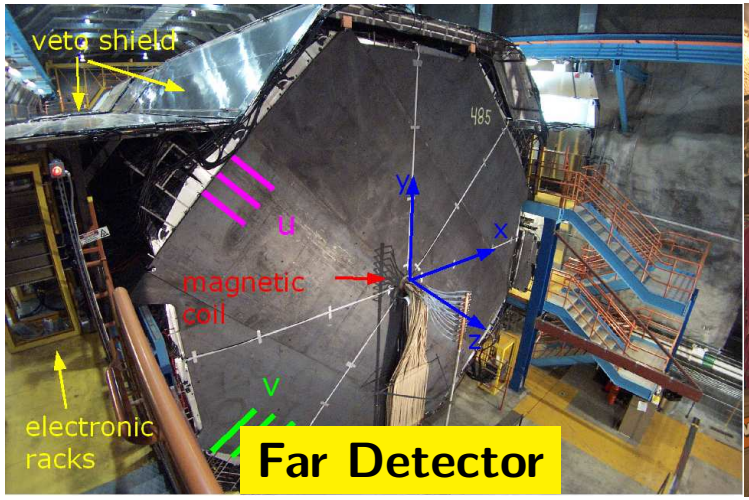
Magnetized iron calorimeters with 2.54 cm thick Fe plates sandwiched with scintillator strips readout by WLS fiber.



- **484 octogonal steel and scintillator plates 8m wide, ⇒ 5.4kTon and 30 m in length.**
- **Toroidal B-field, 1.3 T at r = 2m**
- **Cosmic μ veto shield**

- **282 "squashed" octagonal steel plates, 153 scintillator planes. ⇒ 1kTon and 16 m in length.**
- **Toroidal B-field, 1.3 T at r = 2m**

MINOS Data (2009)

The NuMI beam contains 91.5% ν_μ, 7 % $\bar{\nu}_\mu$ and 1.5% $\nu_e + \bar{\nu}_e$

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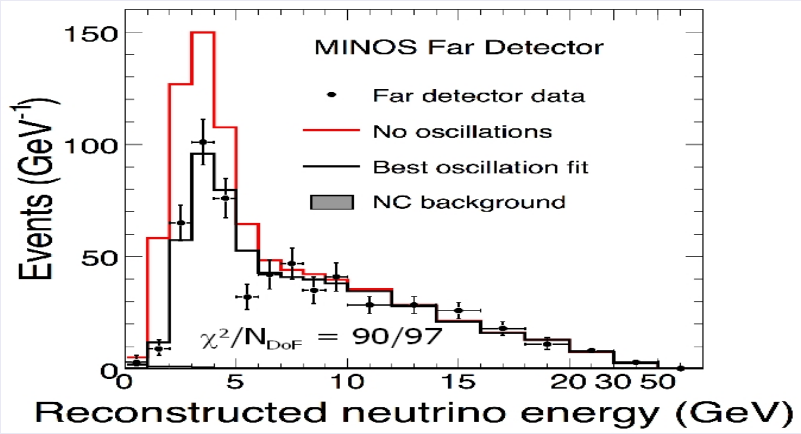
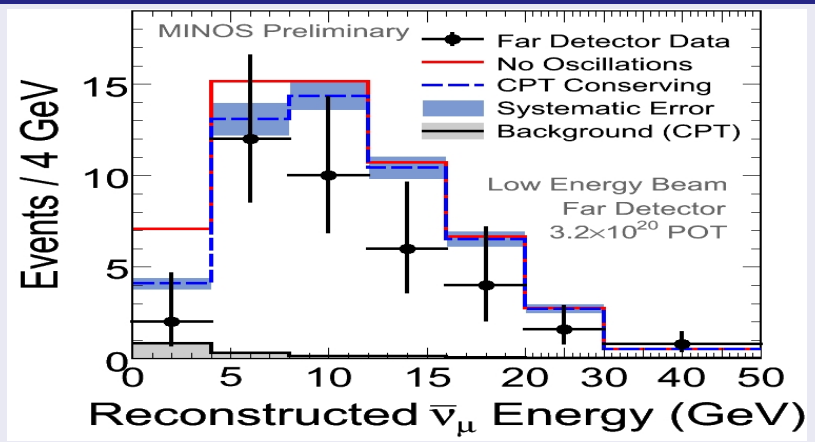
ν_μ disappearance — PRL 101, 2008



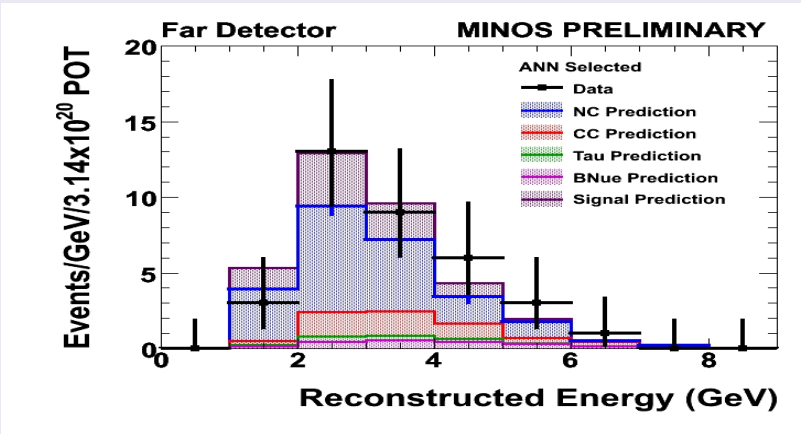
Expected no-osc 1065 $\pm$ 60.
Observe 848.

$\bar{\nu}_\mu$ disappearance — PRL in preparation



Expected (with osc) 58.3 $\pm$ 7.6$_{stat}$ $\pm$ 3.6$_{sys}$.
Observe 42.

ν_e appearance — PRL in preparation



Expected FD background: 27 $\pm$ 5$_{stat}$ $\pm$ 2$_{sys}$.
Observe 35.

MINOS results 2009:

ν_μ Disappearance:

$\Delta m^2_{32} = 2.43 \pm 0.13 \times 10^{-3} eV^2$ **5% accuracy**

$\sin^2 2\theta_{23} > 0.90(90\%C.L.)$

$\bar{\nu}_\mu$ Disappearance:

Fraction $\nu_\mu \rightarrow \bar{\nu}_\mu < 0.026(90\%C.L.)$

ν_e appearance:

$\sin^2 2\theta_{13} < 0.29(90\%C.L.); \Delta m^2 > 0, \delta_{cp} = 0$

$\sin^2 2\theta_{13} < 0.42(90\%C.L.); \Delta m^2 < 0, \delta_{cp} = 0$

Search for ν_s

BNL People and Activities 2008-2009

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Person	Position	MINOS activities
Mary Bishai	Physicist	Beam systematics co-convener Joint MiniBoone/NuMI off-axis analysis (PRL 102, 2009)
Milind Diwan	Physicist	Former ν_e analysis co-convener $\bar{\nu}_\mu$ oscillation analysis internal reviewer
David Jaffe	Physicist	$\bar{\nu}_\mu$ oscillation analysis $\bar{\nu}_\mu$ beam systematics ν_e appearance analysis internal reviewer
Brett Viren	Physicist	Beam data software maintenance and beam simulations
Lisa Whitehead	Research Associate	ν_e appearance analysis
Kevin Zhang	Research Associate	Atmospheric ν_e analysis

MINOS Beam Systematics Group Efforts '08-'09

M. Bishai co-convener

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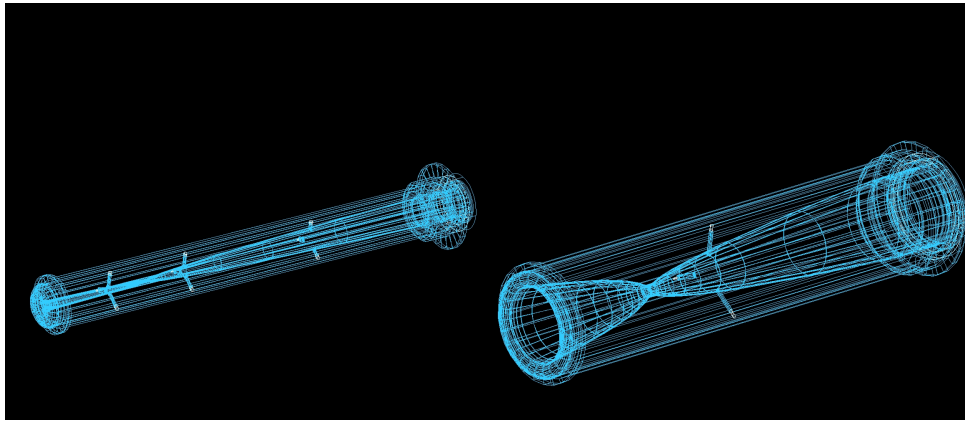

- **Implementation and validation of a detailed NuMI beam-line simulation using the FLUKA08 hadro-production model and GEANT4 geometry. This was necessary to improve the modeling of production in the decay pipe after He was added in 2007 (GEANT3 model is grossly incorrect).**
- **Re-evaluation of hadro-production and geometry systematics with He in the decay pipe and accurate beam-line material for ALL '09-'10 MINOS/NuMI analysis results.**
- **Understanding MINOS near detector spectrum stability.**

M. Bishai heavily involved in validation of new FLUKA08/GEANT4 simulation for the NuMI Beam-line

MINOS ν_μ Spectrum vs Time

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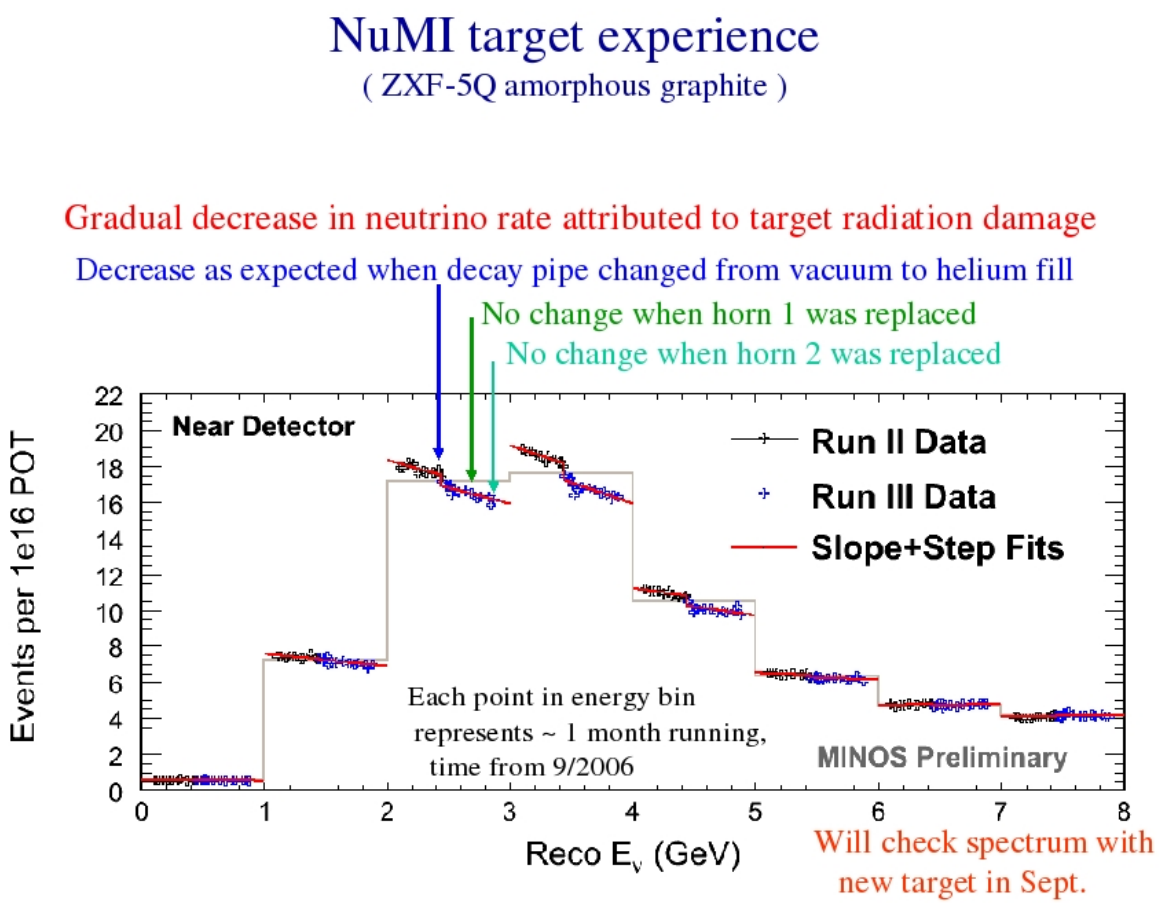

Exposure in MINOS with Target 2:
Run II: $\sim 2 \times 10^{21}$ protons-on-target.
Run III: $> 3 \times 10^{21}$ protons-on-target with He in decay pipe.

Target Radiation Damage

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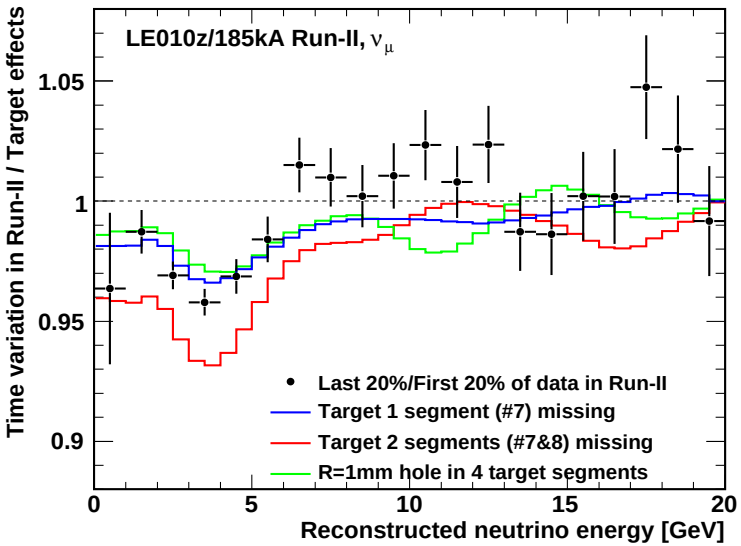
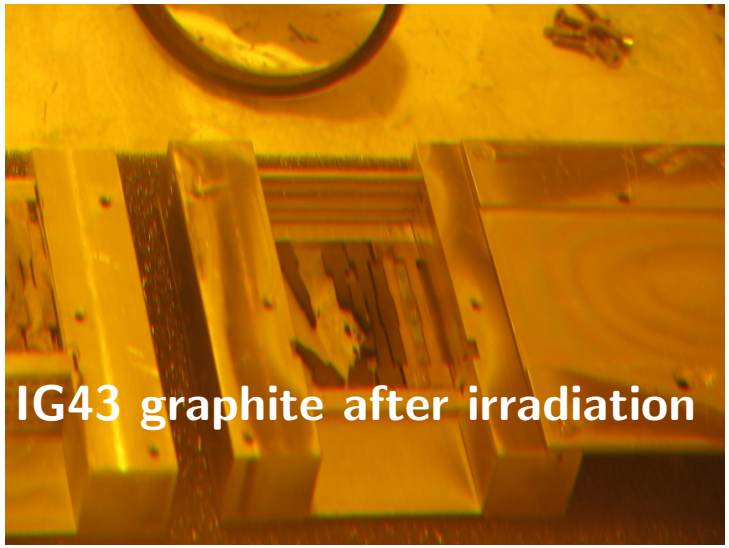
Data from Nick Simos, BNL using 200 MeV proton fluence at BLIP (Brookhaven Linac Isotope Producer) $\sim 10^{21}$ p/cm^2.

This work was carried out independent of the MINOS effort .
M. Bishai's Early Career Research proposal includes request for support for BNL efforts on target irradiation and material R&D for LBNE.





NuMI Target 2 has been exposed to $\sim 10 \times 10^{21}$ 120 GeV p/cm^2.
M. Bishai, D. Jaffe first to demonstrate spectrum change could be caused by target irradiation damage.

Searching for Atmospheric ν_e

Kevin Zhang, David Jaffe

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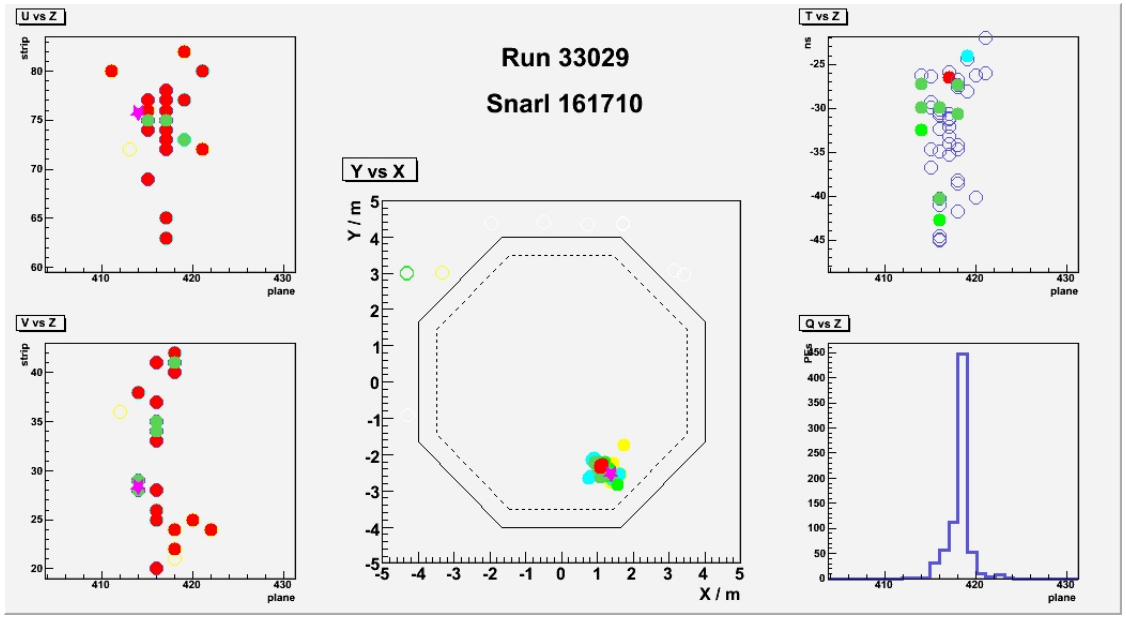
- **Searching for MINOS FD contained showering events outside of the beam spill yields a sample enriched in atmospheric ν_e and neutral-current interactions.**
- **Since these events do not undergo significant oscillations, they are used to normalize the total neutrino flux in the MINOS FD for the atmospheric ν_μ oscillation analysis.**



Atmospheric ν_e Results 24.6 kT-Yrs

Kevin Zhang, David Jaffe

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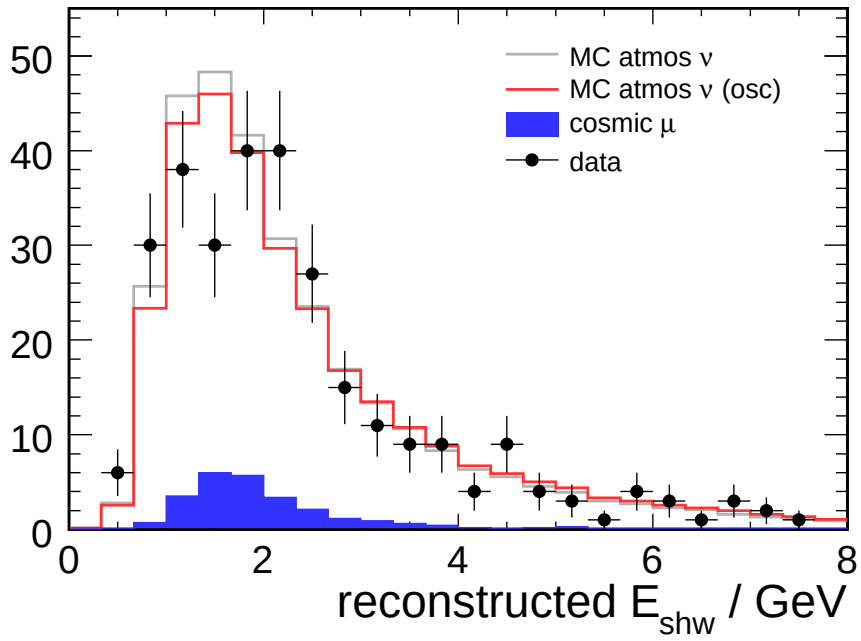

First draft of MINOS atmospheric analysis PRD - including completed atmospheric ν_e analysis - to be circulated to collaboration in September.

Data	Expectation ($\Delta m^2_{32} = 2.5 \times 10^{-3}\text{eV}^2, \sin^2 2\theta_{23} = 1.0$)				
	cosmic μ	$\nu_\mu/\bar{\nu}_\mu$ CC	$\nu_e/\bar{\nu}_e$ CC	$\nu_\tau/\bar{\nu}_\tau$ CC	NC
292	26 ± 3	47 ± 7	159 ± 24	12 ± 2	57 ± 14
292	301 ± 43				

The MINOS ν_e Appearance Search with 3.2×10^{20} p.o.t

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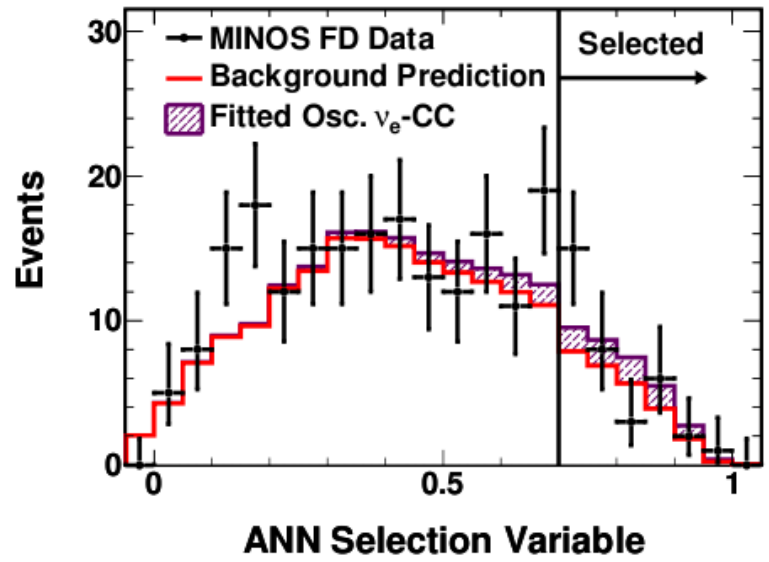

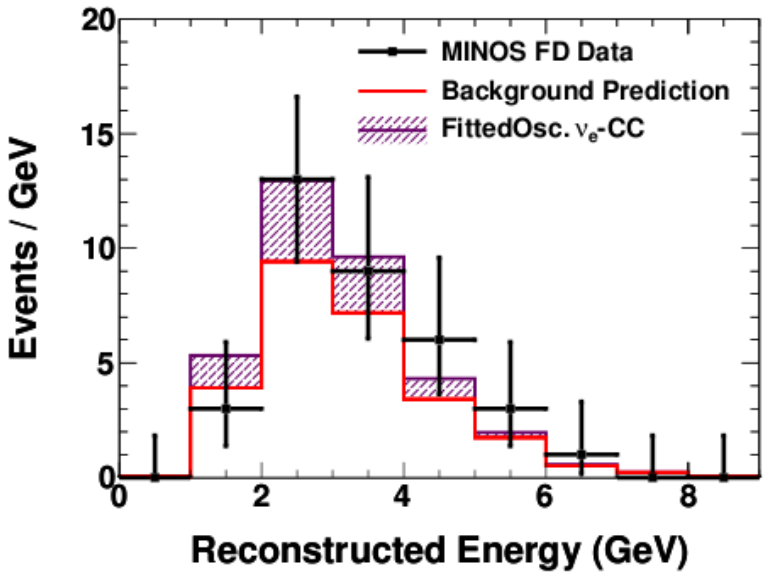

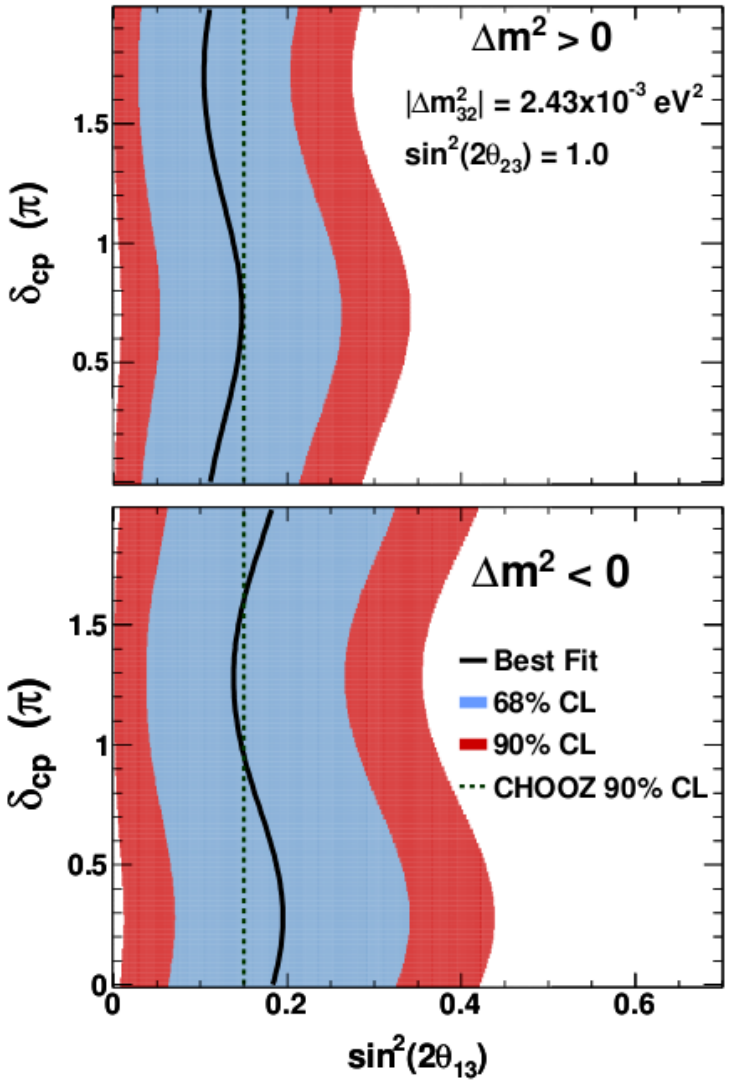

Improving ν_e Sensitivities

Lisa Whitehead

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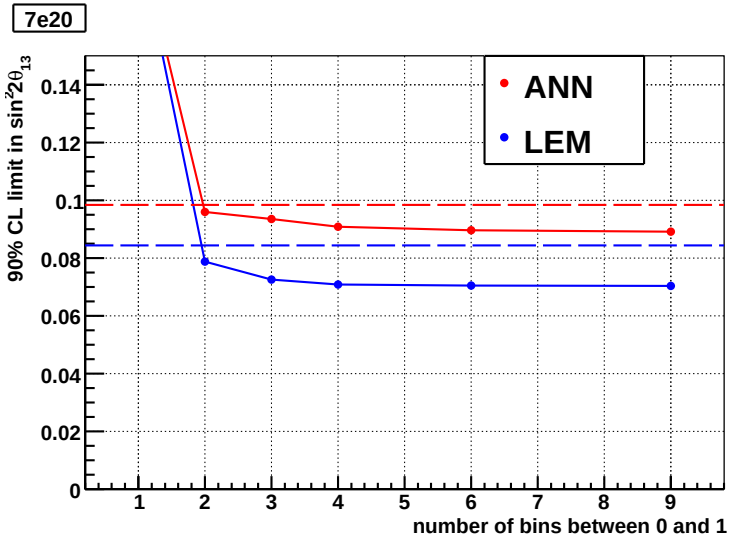
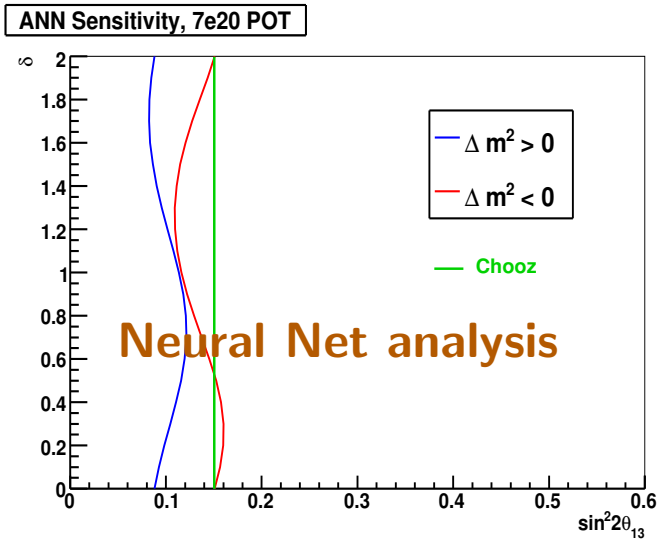
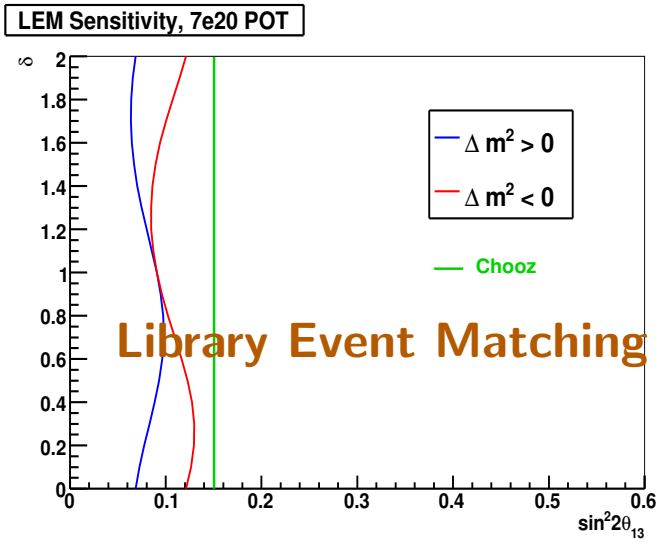
Improve analysis sensitivity by using improved PIDs and energy and PID distributions simultaneously fit for signal and background.

Expected sensitivity with 7×10^{20} p.o.t at 90% C.L:







Improvements in sensitivity using Lisa's techniques will be adopted for the next ν_e analysis result $\sim$ winter 2009

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- **The BNL MINOS group has been involved in a wide variety of successful MINOS analysis efforts: $\bar{\nu}_\mu$ oscillation, ν_e appearance, atmospheric ν_e, beam systematics, joint MiniBoone/NuMI analysis.**
- **The BNL MINOS group in collaboration with other local experts and utilizing unique BNL facilities are providing critical information for understanding MINOS beam data.**
- **BNL group members continue to serve as analysis group co-conveners.**
- **We continue to be responsible for online beam monitoring and beam data quality and proton counting.**
- **The BNL MINOS group's expertise on NuMI/MINOS analysis and beam simulations has been critical in producing the first LBNE beam designs and making the physics case.**